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PROVISIONAL APPLICATION FOR PATENT COVER SHEET

This is a request for filing a PROVISIONAL APPLICATION FOR PATENT under 37 CFR 1.53(c).

Express Mail Label No.

INVENTOR(S)		
Given Name (first and middle [if any])	Family Name or Surname	Residence (City and either State or Foreign Country)
XIAODONG	LI	KIRKLAND, WA

Additional inventors are being named on the 1 separately numbered sheets attached hereto

TITLE OF THE INVENTION (500 characters max)

METHODS AND APPARATUS FOR MULTI-CARRIER, MULTI-CELL WIRELESS COMMUNICATION NETWORKS

Direct all correspondence to: CORRESPONDENCE ADDRESS

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ENCLOSED APPLICATION PARTS (check all that apply)

☒ Specification Number of Pages 9
☐ Drawing(s) Number of Sheets 13
☐ Application Data Sheet. See 37 CFR 1.76
☐ CD(s), Number
☐ Other (specify)

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[Page 1 of 2]

Respectfully submitted,

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REGISTRATION NO.
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TYPED or PRINTED NAME XIAODONG LI

TELEPHONE 425 451 8278

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Number 2 of 2

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Methods and Apparatus for Multi-Carrier, Multi-Cell Wireless Communication Networks

1 Background of the Invention

In multi-carrier wireless communications, many essential system functions such as frequency synchronization and channel estimation are carried out with the facilitation of network information provided by a portion of total subcarriers such as pilot subcarriers (Figure 1). The level of the fidelity of received version of these subcarriers directly dictates how well these functions can be achieved, which in turn affects the performance of the entire network in terms of efficiency and capacity. In a wireless network, there are a number of base stations, each of which provides coverage to its designated area, normally called a cell. If a cell is divided in to sectors, from system engineering point of view each sector can be considered as a cell. In this context, the terms "cell" and "sector" are interchangeable. The network information can be categorized into two types: the cell-specific information that is unique to a particular cell and the common information that is common to the entire network or to a portion of the entire networks (e.g., a group of cells). In a multi-cell environment, for example, the base station transmitter of each cell transmits its own pilot subcarriers, in addition to data carriers, for the use by the receivers within the cell. In such an environment, carrying out the pilot-dependent functions becomes a challenging task in that, in addition to the degradation due to multipath propagation channel, signals originated from the base stations at different cells interfere with each other. One approach to deal with the interference problem is that each cell will transmit a particular pattern of pilot subcarriers based on a certain type of cell-dependent random process, which, to a certain degree, is able to mitigate impact of the mutual interference between the pilot subcarriers from adjacent cells [1]. However, in this approach or alike, there is no careful and systematic consideration of the unique requirements for pilot subcarriers of different functionalities. While it is necessary to manage the mutual interference between those subcarriers that are used for the functionalities unique to individual cells, it is desirable and constructive to design those subcarriers that are used to carry common information in such a way that signals from other cells are treated as contributing factors rather than interfering factor.

2 Summary of the Invention

In this invention, a design process is devised to divide pilot subcarriers into two different groups according to their functionalities and hence their distinct requirements. Each group of pilot subcarriers will be designed to have such a transmit format that the essential system functions such as frequency synchronization and channel estimation can be performed in the optimal way. The first group is called cell-specific pilot subcarriers (Figure 5), which will be used for the receiver to extract information unique to each individual cell. For example, these cell-specific pilot subcarriers can be used in the channel estimation process where it is necessary for a particular receiver to be able to differentiate the pilot subcarriers that are intended for its use

from those that are from other cells. For these pilot subcarriers, counter-interference methods are necessary. The second group is termed the common pilots subcarriers (Figure 5), which are designed to possess a set of characteristics common to all the base stations of the system. Thus, every receiver within the system is able to exploit these common pilot subcarriers to perform the necessary functions without interference problem. For instance, these common pilot subcarriers can be used in the frequency synchronization process, where it is not necessary to discriminate pilot subcarriers from one cell to others but it is desirable for the receiver to combine coherently the energy of common pilot subcarriers with the same carrier index from different cells so as to achieve relatively accurate frequency estimation.

This invention provides methods to define the transmission formats of the cell-specific and common pilot subcarriers that enable a receiver to perform different essential system functions. In particular, a set of design criteria are provided for pilot subcarriers.

This invention further provides the apparatus or means to implement the aforesaid design process and methods. In particular, signal reception can be improved by manipulating phase values of the pilot subcarriers and by the use of power control The methods and process provided by this invention can also be extended to cases, such as the one where multiple antennas are used within an individual sector and where some subcarriers are used to carry common network/system information. Base stations can be synchronized in frequency and time by sharing a common frequency oscillator or a common frequency reference signal, such as the one generated from the signals provided by the Global Positioning System (GPS).

3 Brief Description of the Drawings

Figure 1: A basic multi-carrier wireless communication system consists of a transmitter and a receiver. A functional block, called Pilot generation and insertion, at the transmitter generates the necessary pilot subcarriers and inserts them into the predetermined locations in frequency. These pilot subcarriers are used by the receiver to carry out some essential functions.

Figure 2: The basic structure of a multi-carrier signal in the frequency domain is made up of subcarriers. Data subcarriers can be grouped into subchannels in a particular way. The pilot subcarriers are also distributed over the entire channel in a particular way.

Figure 3: The radio resource is divided into small units in both the frequency and time domains: subchannels and time slots. The basic structure of a multi-carrier signal in the time domain is made up of time slots.

Figure 4: A cellular wireless network is comprised of a plurality of cells, in each of which the coverage is provided by a base station (BS). Within each coverage area, there are distributed mobile stations. A base station is connected to the backbone of the network via a dedicated link and also provides radio links to the mobile stations within its coverage.

Figure 5: The pilot subcarriers are divided into two groups: cell-specific pilot subcarriers and common pilot subcarriers. The cell-specific pilot subcarriers for different cells are not necessarily aligned in frequency. They can be used for the receiver to extract the cell-specific information. The common pilot subcarriers for different cells are normally

aligned in frequency. They are designed to possess a set of attributes common to all the base stations within the network. Thus, every receiver within the system is able to exploit these common pilot subcarriers without interference problem. The power of the pilot subcarriers can be varied through a particular power control scheme and based on a specific application.

Figure 6: An embodiment of implementation of the pilot-generation-and-insertion functional block in Figure 1 is shown to have a microprocessor for generating the pilot subcarriers and for inserting them into the frequency sequence contained in the electronic memory.

Figure 7: The common pilot subcarriers are generated by the microprocessor in Figure 6 to realize phase diversity.

Figure 8: An embodiment of the implementation of delay diversity is shown to create the equivalent effect of phase diversity by adding a random delay time duration, either in baseband or RF, to the time-domain signals.

Figure 9: Two examples are shown for extension to multiple antenna applications. (a) In the case where there is only one transmission branch that are connected to an array of antennas through a transformer, the implementation is exactly the same as in the case of single antenna. (b) In the case where there are a plurality of transmission branches that are connected to different antennas, the cell-specific pilot subcarriers for transmission branches are usually defined by the multiple-antenna scheme whereas the common pilot subcarriers for each transmit branch are generated to meet the criteria specified in this invention.

Figure 10: An embodiment of implementation of the synchronization in frequency and time of two collocated base stations via sharing a common frequency oscillator. Mobile stations covered by these two base stations do not experience interference when receiving the common pilot subcarriers.

Figure 11: An embodiment of implementation of the synchronization in frequency and time base stations at different locations via sharing a common frequency reference signal generated from the GPS signals. Mobile stations covered by these two base stations do not experience interference when receiving the common pilot subcarriers.

Figure 12: In one embodiment of implementation, the wireless network consists of two groups of cells (or sectors) and base stations in each group share their own set of common pilot subcarriers. In this scenario, only those base stations within their group are required to synchronize to a common reference. While the common pilot subcarriers within each group are designed to meet the criteria defined in this invention, a particular counter-interference process (e.g., randomization in frequency) will be applied to different sets of common pilot subcarriers.

Figure 13: All the base stations within the network transmit, along with a common pilot subcarrier, a data subcarrier carrying the data information common to all the cells in network. A receiver within the network can determine the composite channel coefficient based the common pilot subcarrier and apply it to the data subcarrier to compensate for the channel effect, thereby recovering the data information.

4 Detailed Description

4.1 Multi-Carrier Communication System

In a multi-carrier communication system such as multi-carrier code division multiple access (MC-CDMA) and orthogonal frequency division multiple access (OFDMA), information data are multiplexed on subcarriers that are mutually orthogonal in the frequency domain. In effect, a frequency selective channel is broken into a number of parallel but small segments in frequency that can be treated as flat fading channels and hence can be easily dealt with using simple one-tap equalizers. The (de)modulator can be carried out using the fast Fourier transform (FFT).

The physical media resource (e.g., radio or cable) in a multi-carrier communication system can be divided in both the frequency and time domains. This canonical division provides a high flexibility and fine granularity for resource sharing.

The basic structure of a multi-carrier signal in the frequency domain is made up of subcarriers. Within a particular spectral band or channel, there are a fixed number of subcarriers. There are three types of subcarriers:

1. Data subcarriers, which carries information data;
2. Pilot subcarriers, whose phases and amplitudes are predetermined and made known to all receivers and which are used for assisting system functions such as estimation of system parameters; and
3. Silent subcarriers, which have no energy and are used for guard bands and DC carrier.

The data subcarriers can be arranged into groups called subchannels to support both scalability and multiple access. The subcarriers forming one subchannel are not necessarily adjacent to each other. The concept is illustrated in Figure 2.

The basic structure of a multi-carrier signal in the time domain is made up of time slots to support multiple-access. The resource division in both the frequency and time domains is depicted in Figure 3.

In multi-carrier communication system, a generic transmitter may consist of the following functional blocks (Figure 1):

1. Encoding and modulation
2. Pilot generation and insertion
3. Inverse fast Fourier transform (IFFT)
4. Transmission

A generic receiver may consist of the following functional blacks:

1. Reception
2. Frame synchronization
3. Frequency and timing compensation
4. Fast Fourier transform (FFT)

5. Frequency, timing, and channel estimation
6. Channel compensation
7. Decoding

4.2 Cellular Wireless Networks

In a cellular wireless network, the geographical region to be serviced by the network is normally divided into smaller areas called cells. In each cell the coverage is provided by a base station. Thus, this type of structure is normally referred to as the cellular structure (Figure 4). Within each coverage area, there are located mobile stations to be used as an interface between the users and the network. A base station is connected to the backbone of the network, usually by a dedicated link. A base station also serves as a focal point to distribute information to and collect information from its mobile stations by radio signals.

In a wireless network, there are a number of base stations, each of which provides coverage to its designated area, normally called a cell. If a cell is divided in to sectors, from system engineering point of view each sector can be considered as a cell. In this context, the terms "cell" and "sector" are interchangeable.

In the consideration of a M-cell wireless network, which can be one-way or two-way either time division duplex or frequency division duplex, the transmitters at all the cells are synchronized via a particular means and are transmitting simultaneously. In a particular cell, say the p^{th} cell, a receiver receives a signal at a particular subcarrier, say the n^{th} subcarrier at time t_k, which can be described as

$$s_i(t_k) = a_{i,p}(t_k)e^{j\varphi_{i,p}(t_k)} + \sum_{\substack{m=1 \\ m \neq p}}^{M} a_{i,m}(t_k)e^{j\varphi_{i,m}(t_k)} \tag{1}$$

where $a_{i,m}(t_k)$ and $\varphi_{i,m}(t_k)$ denote the signal amplitude and phase, respectively, associated with the i^{th} subcarrier from the base station of m^{th} cell.

4.3 Cell-Specific Pilot Subcarriers

If the i^{th} subcarrier is used as a pilot subcarrier at the p^{th} cell for the cell-specific purposes, the cell-specific information carried by $a_{i,p}(t_k)$ and $\varphi_{i,p}(t_k)$ are of interest to the receiver at the p^{th} cell and other signals described by the second term on the right hand side of (1) are considered to be interference, which is an incoherent sum of signals from other cells. In this case, a sufficient level of the carrier-to-interference ratio (CIR) is required to obtain the estimates of $a_{i,p}(t_k)$ and $\varphi_{i,p}(t_k)$ with desirable accuracy. There are many ways to boost the CIR. For examples, the amplitude of a pilot subcarrier can be set larger than that of a data subcarrier; power control can be applied to the pilot subcarriers; and cells adjacent to the p^{th} cell may avoid using the i^{th} subcarrier as pilot subcarrier. All these can be achieved with coordination between cells based on a certain process.

4.4 Common Pilot Subcarri rs

The common pilot subcarriers for different cells are normally aligned in the frequency index (Figure 5). If the i^{th} subcarrier is used as a pilot subcarrier at the p^{th} cell for the common purposes, it is not necessary to consider the second term on the right hand side of (1) to be interference. Instead, this term can be turned into a coherent component of the desirable signal by designing the common pilot carriers to meet the criteria specified in this invention, provided that base stations at all cells are synchronized in frequency and time. In such a case, which cell the receiver is located become irrelevant and consequently, the received signal can be rewritten as

$$s_i(t_k) = \sum_{m=1}^{M} a_{i,m}(t_k) e^{j\varphi_{i,m}(t_k)} \tag{2}$$

The common pilot subcarriers can be used for a number of functionalities, such as frequency offset estimation and timing estimation.

To estimate the frequency, signals at different times are normally involved. In the example of two common pilot subcarriers of the same frequency index but at different time, the received signal at time t_{k+1}, with respect to the signal at time t_k, is given by

$$s_i(t_{k+1}) = e^{j2\pi f_i \Delta t} \sum_{m=1}^{M} a_{i,m}(t_{k+1}) e^{j\varphi_{i,m}(t_{k+1})} \tag{3}$$

where $\Delta t = t_{k+1} - t_k$. If Δt is much less than the coherence period of the channel and the following requirements are met, which are,

$$a_{i,m}(t_k) = c_i a_{i,m}(t_{k+1}) \tag{4}$$

and

$$\varphi_{i,m}(t_k) = \varphi_{i,m}(t_{k+1}) + \beta_i \tag{5}$$

where $c_i > 0$ and $-\pi \le \beta_i \le \pi$ are predetermined constants for all values of m, In this case, then the frequency can be determined by

$$2\pi f_i \Delta t = \arg\{s_i^*(k) s_i(k+1)\} - \beta_i \tag{6}$$

From all the frequency estimates $\{f_i\}$, an offset can be derived based on a particular criteria.

For timing estimation, multiple common pilot carriers are normally required. In the example of two common pilot subcarriers, the received signal at f_n, is given by

$$s_n(t_k) = e^{j2\pi \Delta f T_s(t_k)} \sum_{m=1}^{M} a_{n,m}(t_k) e^{j\varphi_{n,m}(t_k)} \tag{7}$$

where $\Delta f = f_n - f_i$ and T_s denotes the sampling period. If Δf is much less than the coherence bandwidth of the channel and the following requirements are met, which are

$$a_{i,m}(t_k) = c(t_k)a_{n,m}(t_k) \tag{8}$$

and

$$\varphi_{i,m}(t_k) = \varphi_{n,m}(t_k) + \gamma(t_k) \tag{9}$$

where $c(t_k) > 0$ and $-\pi \le \gamma(t_k) \le \pi$ are predetermined constants for all values of m., then, T_s can be determined by

$$2\pi\Delta f T_s(t_k) = \arg\{s_i^*(t_k)s_n(t_k)\} - \gamma(t_k) \tag{10}$$

In one embodiment of implementation illustrated in Figure 6, a microprocessor embedded in the pilot-generation-and-insertion functional block computes the attributes of the pilot subcarriers such as their frequency indices and complex values specified by their requirements, and insert them into the frequency sequence contained in the electronic memory, such as a RAM, ready for the application of IFFT.

4.5 Diversity for Common Pilot Subcarriers

Referring to (2), which is a sum of a number of complex signals. It is possible that these signals superimpose together destructively, thereby causing the amplitude of the receiver signal at this particular subcarrier to be so small that the signal itself becomes relatively unreliable. To deal with this adverse effect, phase diversity can be used. In the example of frequency estimation, a random phase $\vartheta_{l,m}$ can be added to another pilot subcarrier, say the l^{th} subcarrier; that is,

$$\varphi_{l,m}(t_k) = \varphi_{i,m}(t_k) + \vartheta_{l,m} \tag{11}$$

and

$$\varphi_{l,m}(t_{k+1}) = \varphi_{i,m}(t_{k+1}) + \vartheta_{l,m} \tag{12}$$

where $\vartheta_{l,m}$ should be set differently for each cell, provided that the following condition is met,

$$\varphi_{l,m}(t_k) = \varphi_{l,m}(t_{k+1}) + \beta_l, \quad \text{for all values of } m \tag{13}$$

With the phase diversity, it is expected that the probability that both $|s_i(t_k)|$ and $|s_l(t_k)|$ will diminish at the same time is relatively small. The embodiment of implementation of phase diversity is depicted in Figure 7. It should be noted that time delay will achieve the equivalent diversity effect, and another embodiment of implementation is illustrated in Figure 8. A random delay time duration is added, either in baseband or RF, to the time-domain signals to create the equivalent effect of phase diversity.

4.6 Power Control for Pilot Subcarriers

In one embodiment of implementation, power control can be applied to the pilot subcarriers. The power of the pilot subcarriers can be adjusted individually or as a subgroup to

1. meet the needs of their functionalities;
2. adapt to the operation environments (e.g., propagation channels); and
3. reduce interference between cells or groups of cells.

In one embodiment of implementation, power control is implemented differently for cell-specific pilot subcarriers and common pilot subcarriers. For example, stronger power is applied to common pilot subcarriers than to the cell-specific subcarriers.

4.7 Application to Multiple Antennas

The methods and process provided by this invention can also be implemented in applications where multiple antennas are used within an individual sector, provided that the criteria specified either by (4) and (5) for frequency estimation or by (8) and (9) for timing estimation are satisfied. In Figure 9, there are two examples of such extension to multiple antenna applications. In the case where there is only one transmission branch that is connected to an array of antennas through a transformer (e.g., a beamforming matrix), the implementation is exactly the same as in the case of single antenna. In the case where there are a plurality of transmission branches that are connected to different antennas (e.g., in a transmit diversity scheme or a multiple-input multiple-output scheme), the cell-specific pilot subcarriers for transmission branches are usually defined by the multiple-antenna scheme whereas the common pilot subcarriers for each transmission branch are generated to meet the requirements by (4) and (5) for frequency estimation or by (8) and (9) for timing estimation.

4.8 Joint-Use of Cell-Specific and Common Pilot Subcarriers

In one embodiment of implementation, both the cell-specific and common pilot subcarriers can be used jointly in the same process based on certain information theoretic criteria, say the optimization of the signal-to-noise ratio. For example, in the estimation of a system parameter (e.g. frequency), some or all cell-specific subcarriers, if they satisfy a certain criterion, say to exceed a CIR threshold, may be selected to be used together with the common pilot subcarriers to improve estimation accuracy. Furthermore, the common pilot subcarriers can be used along with the cell-specific subcarriers to determine the cell-specific information in some scenarios, one of which is the operation at the edge of the network.

4.9 Base Transmitters Synchronization

One of the requirements is that base stations at all cells are synchronized in frequency and time. In one embodiment of implementation, the base station transmitters that are collocated, as in the case where a cell is divided into sectors and the base stations of these sectors are physically placed at the same location, are locked to a single frequency oscillator, as shown in Figure 10, whereas the base station transmitters that are located at different areas are locked to a common reference frequency source, such as the GPS signal as shown in Figure 11.

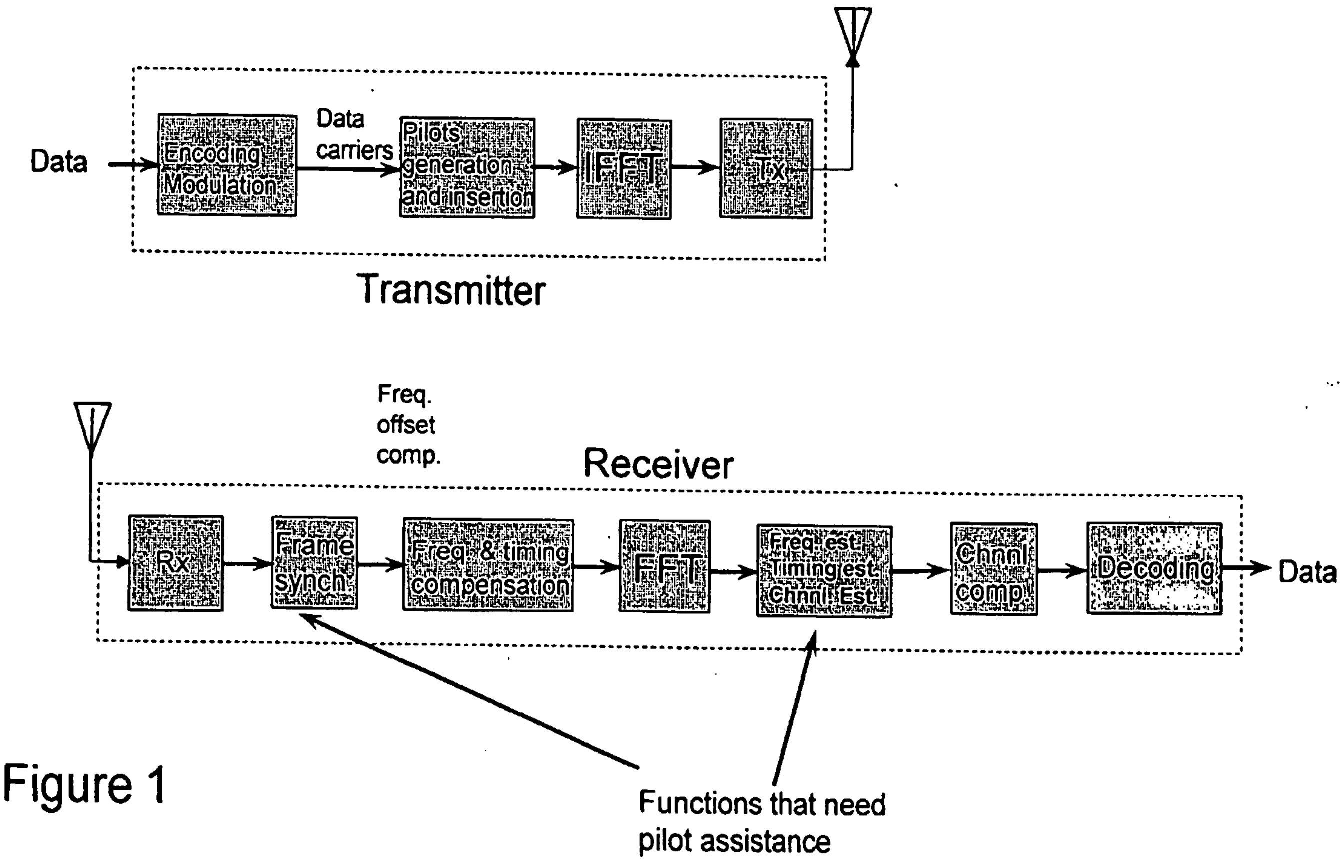
In some applications, the entire wireless network may consist of multiple groups of cells (or sectors) and each group may have its own set of common pilot subcarriers. In this scenario, only those base stations within their group are required to synchronize to a common reference. While the common pilot subcarriers within each group are designed to meet the criteria defined by (4) and (5) or by (8) and (9) for the use by its base stations, a particular counter-interference process (e.g., randomization in frequency or power control) will be applied to different sets of common pilot subcarriers so that the signals from the cells within the same group add coherently while the signals from the cells in other groups are treated as randomized interference. One embodiment of such implementation is illustrated in Figure 12, where Cells A1, A2, and A3 are conventional "sectors" belonging to one base station.

4.10 Extension to Transmission of Data Information

In one embodiment of implementation, all the design processes, criteria, and methods described in this invention can be extended to applications where common network information is required to be distributed to all receivers within the network. In one example, all the base stations within the network transmit, along with some common pilot subcarriers, an identical set of data subcarriers in which is imbedded the data information common to all the cells in the network (Figure 13). A receiver within the network can estimate the coefficients of the composite channel from the common pilot subcarriers and apply them to the data subcarriers to compensate for the channel effects, thereby recovering the data information.

Reference

[1] IEEE Standard for Local and Metropolitan Area Networks, Part 16: Air Interface for Fixed Broadband Wireless Access Systems - Medium Access Control Modifications and Additional Physical Layer Specifications for 2-11 GHz.



Data
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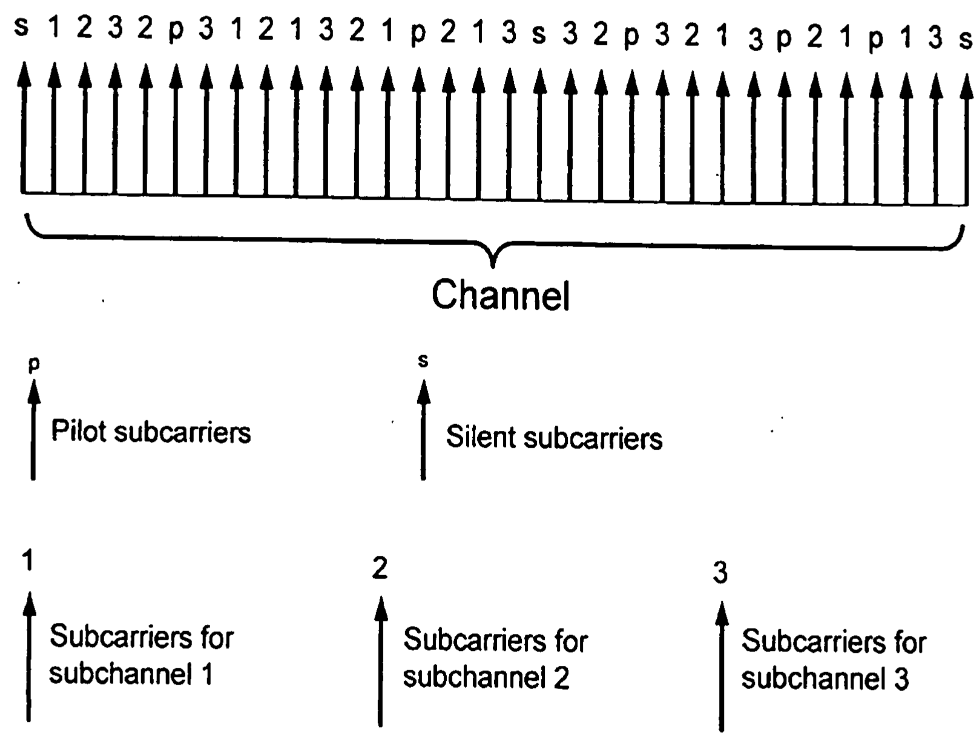
Figure 1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Channel
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Pilot subcarriers
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Silent subcarriers
1
Subcarriers for subchannel 1
2
Subcarriers for subchannel 2
3
Subcarriers for subchannel 3

Figure 2

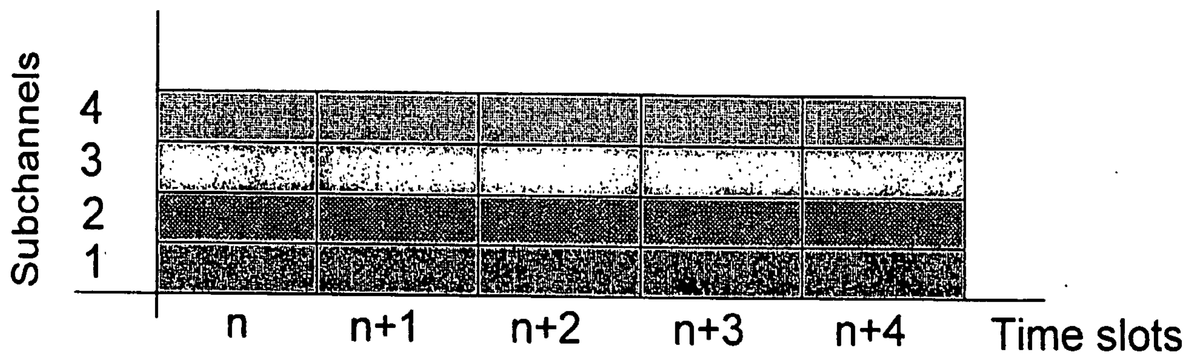


Figure 3

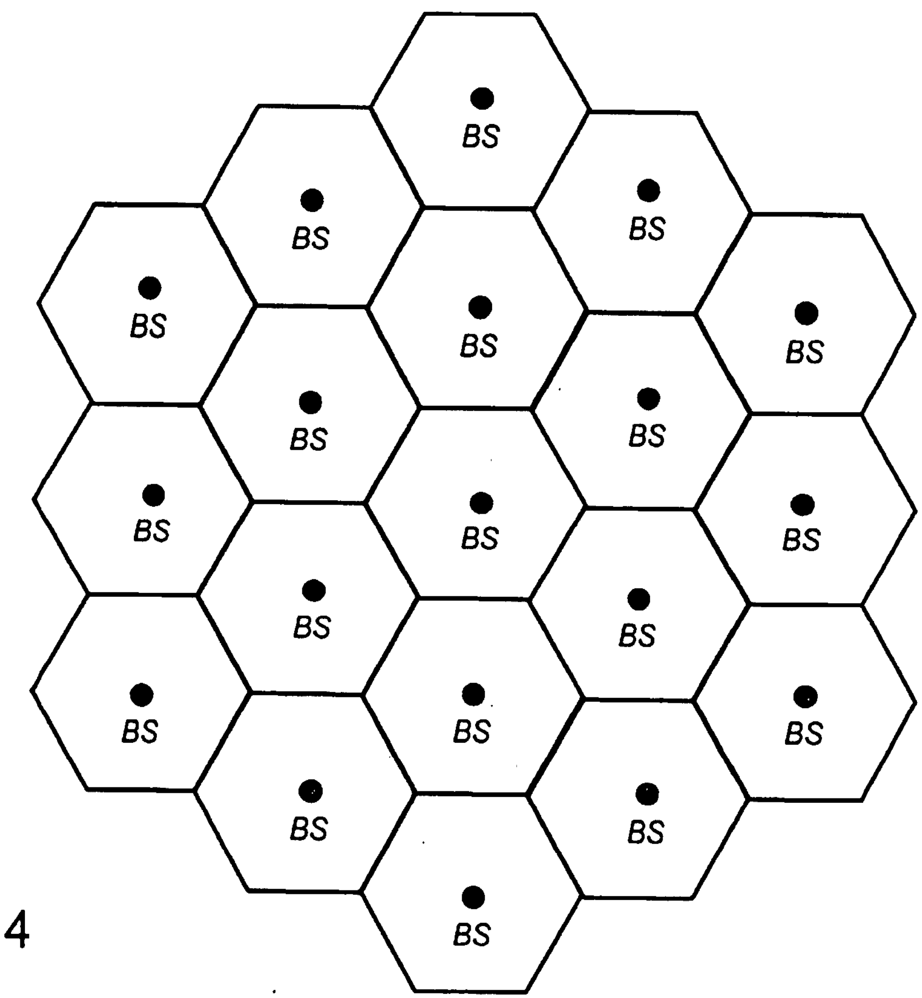
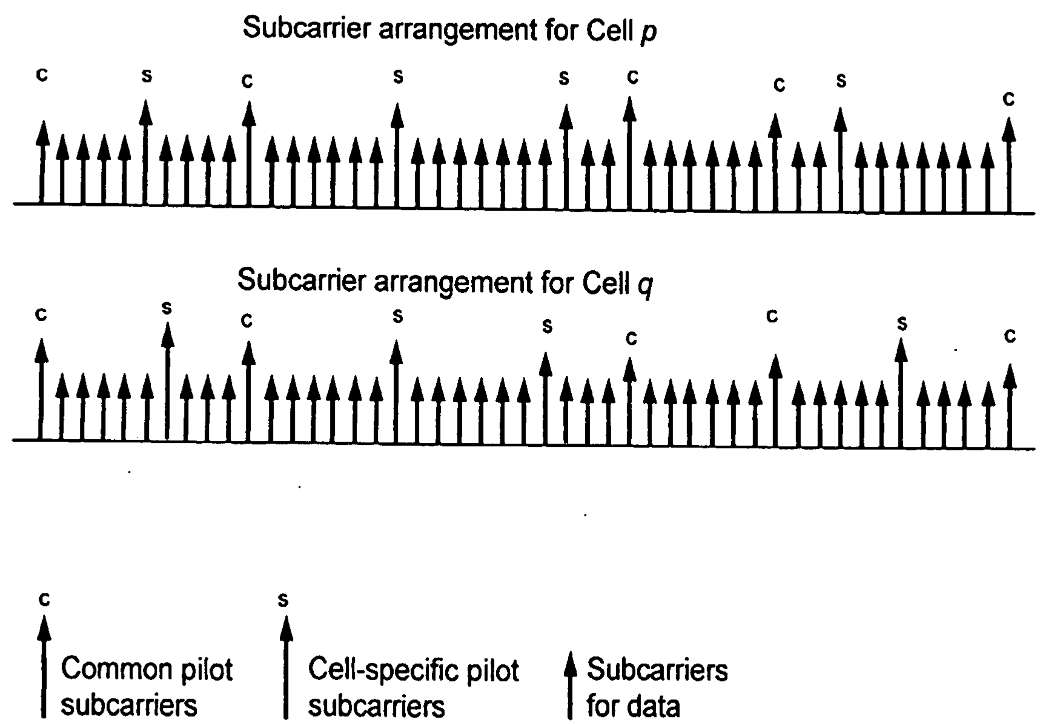


Figure 4



Subcarrier arrangement for Cell p
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Subcarrier arrangement for Cell q
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Common pilot subcarriers
s
Cell-specific pilot subcarriers
Subcarriers for data

Figure 5

Pilot generation and insertion functional block

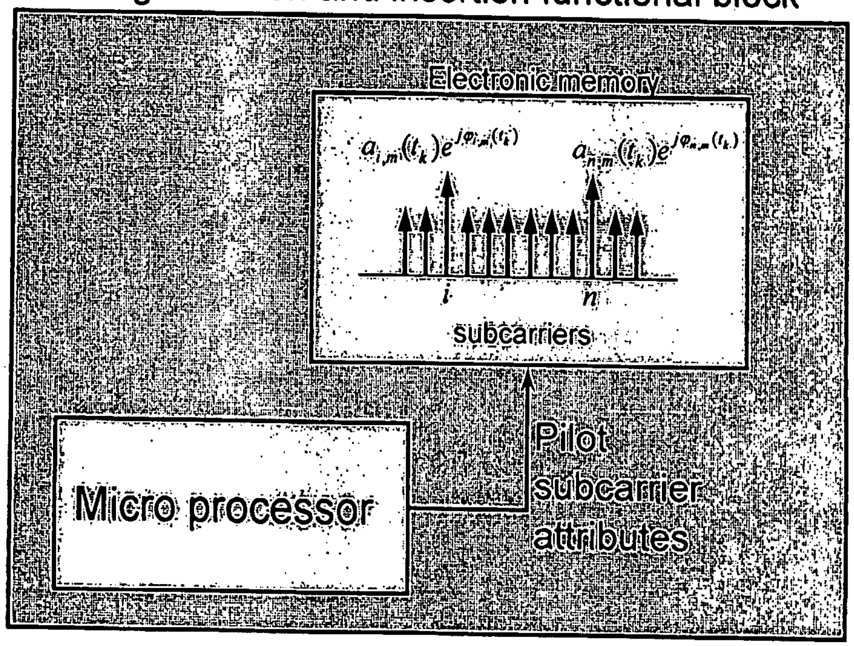
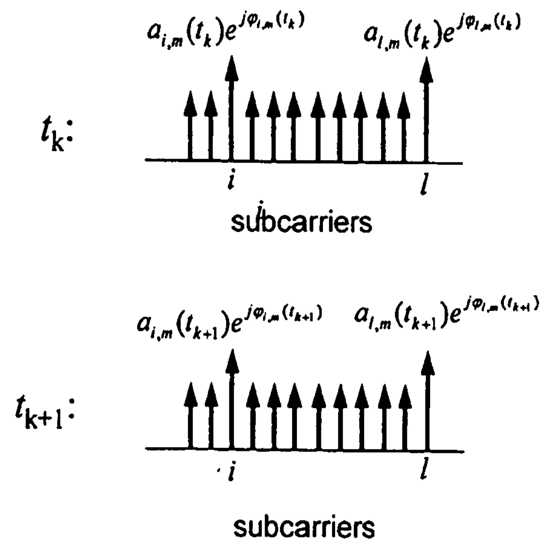


Figure 6



$$\varphi_{l,m}(t_k) = \varphi_{i,m}(t_k) + \vartheta_{l,m}$$

$$\varphi_{l,m}(t_{k+1}) = \varphi_{i,m}(t_{k+1}) + \vartheta_{l,m}$$

Figure 7

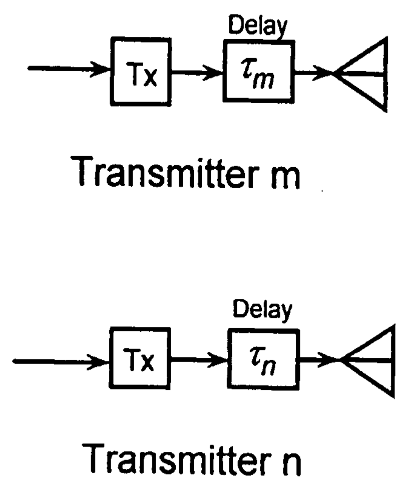
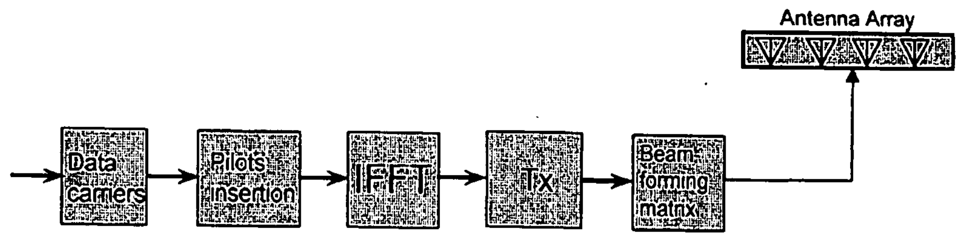
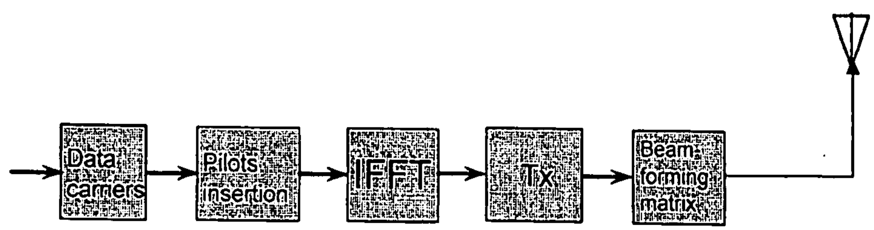


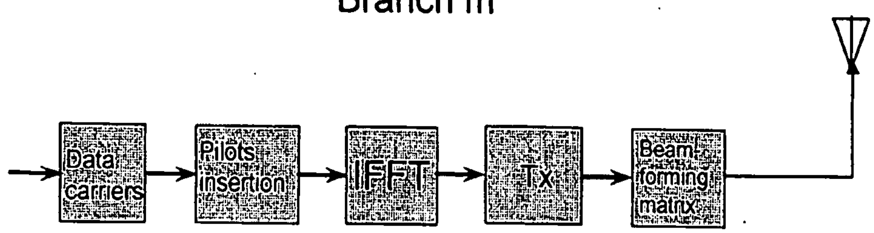
Figure 8



(a)



Branch m

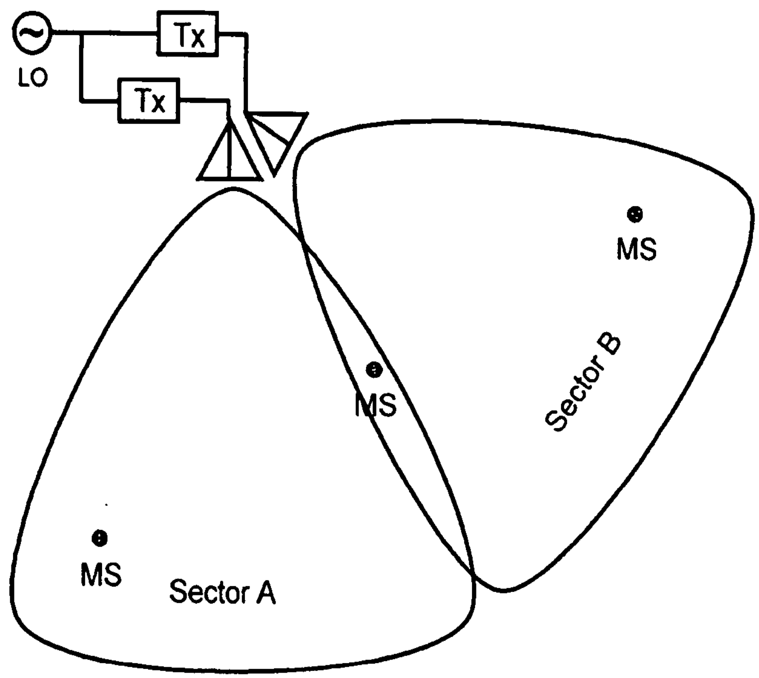


Branch n

Figure 9

(b)

Figure 10



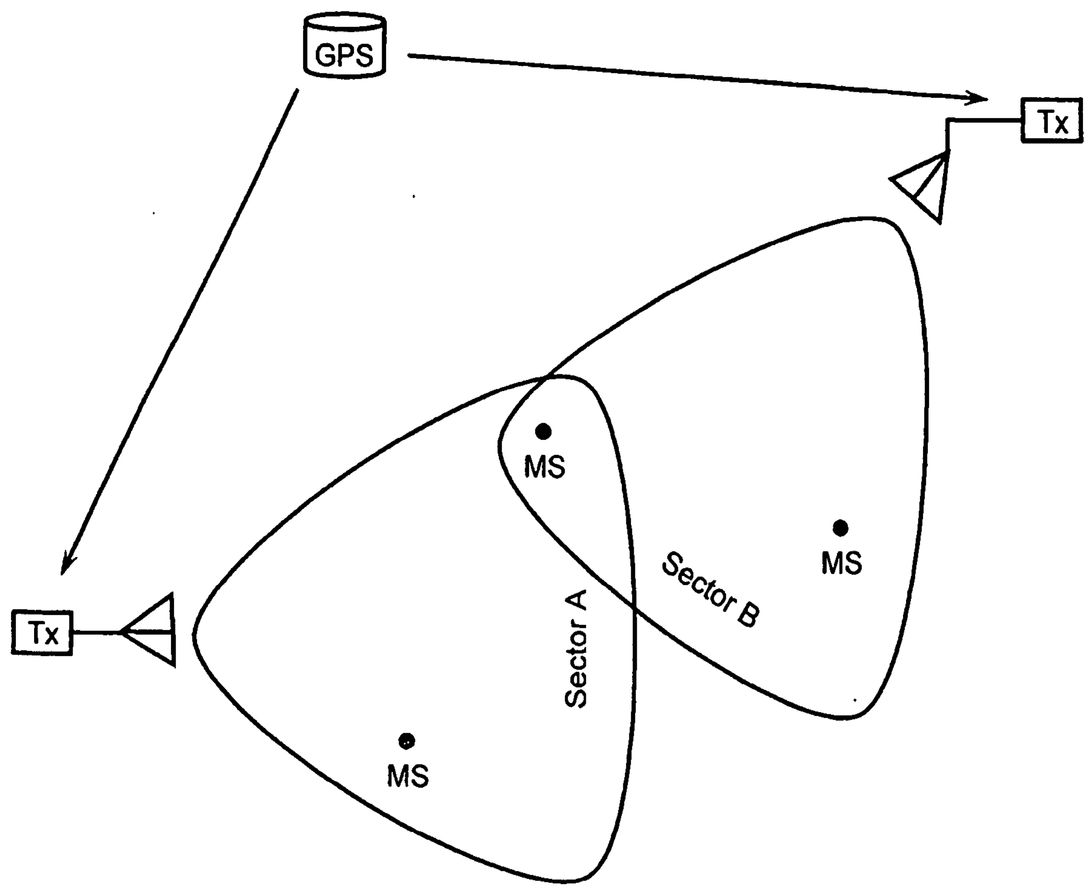


Figure 11

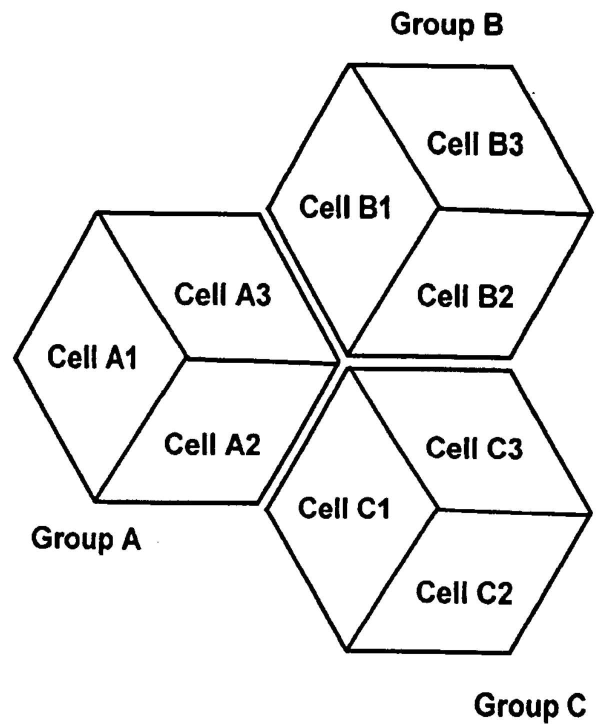
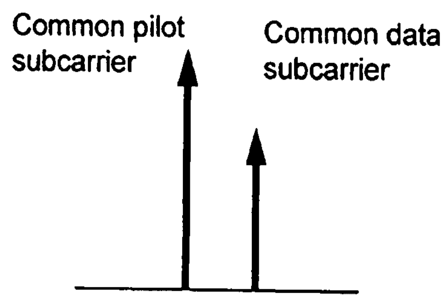
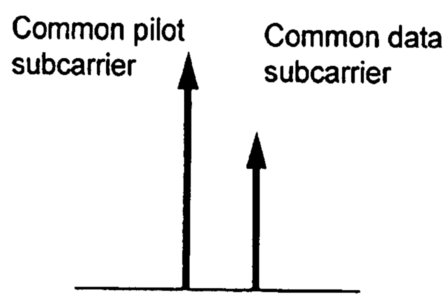

Group B
Cell B3
Cell B1
Cell B2
Cell A3
Cell A1
Cell A2
Cell C3
Cell C1
Cell C2
Group A
Group C

Figure 12



Common subcarrier arrangement for Cell p



Common subcarrier arrangement for Cell q

Figure 13